Electromagnetic calorimeter prototype for the SoLID project at Jefferson Lab

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JLab 12GeV upgrade

Maximum electron beam energy upgraded from 6GeV to 12GeV.

Upgrade includes both accelerator and detector in each Hall.

Continuous Electron Beam Accelerator Facility (CEBAF)
SoLID project and EM calorimeter (Solenoidal Large Intensity Device)

- SoLID proposed in Hall A for 5 approved experiment in 12 GeV era.
  - Requires high luminosity and large acceptance.
- Two detector configurations:
  - “SIDIS” (Semi-Inclusive Deep Inelastic Scattering)
  - “PVDIS” (Parity-Violating Deep Inelastic Scattering)
  - Electromagnetic calorimeter(EC) shared in both configurations
EC Design Requirements

1. Provide trigger: coincidence with Cherenkov detector, suppress background

2. Electron- hadron separation:
   - >100:1 π rejection;
   - Electron efficiency > 95%;

3. Provide shower position to help tracking/suppress background
   - σ ~ 1 cm

4. Modules easily swapped and rearranged for PVDIS ↔ SIDIS;
Shashlik EC Longitudinal design

- Preshower: 2 $X_0$ lead + 20 mm plastic scintillator, WLS fiber embedded in scintillator.
- Shower: shashlik module (0.5mm lead + 1.5mm scintillator + 0.1mm paper sheet×2) ×194, WLS fiber×96 penetrating layers longitudinally.
- Overall: 20 $X_0$(<2% leakage), energy resolution less than 10%/\sqrt{E}$(GeV)
Shashlik EC Lateral design

Good balance between resolution, background and cost (simulation) for 100cm² block size.

- 100 cm² of hexagon shape with 6.25cm side length
Main materials in Shashlik EC detector

- Scintillator Tile:
  - Manufacture in Kedi, China
  - Casting with special mould
  - 2 formulas: normal/enhanced
  - Match the absorption spectrum of WLS fiber

- Lead Plate: punching

- Reflection Layer: print paper

- WLS Fiber:
  - BCF91A (Saint-Gobain)
  - Y11 (Kuraray)
Reflector layer selection

Reflector material
- No reflector
- Printing Paper
- Aluminum foil
- Tyvek paper
- MCPET

Relative light yield
- No reflector: 0.85±0.02
- Printing Paper: 1.00±0.06
- Aluminum foil: 0.97±0.08
- Tyvek paper: 1.61±0.16
- MCPET: 1.24±0.05

Cosmic ray test setup: 5 layers of shashlik style

The Distribution of Photoelectrons

<table>
<thead>
<tr>
<th>Entries</th>
<th>3829</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>42.65</td>
</tr>
<tr>
<td>RMS</td>
<td>38.59</td>
</tr>
<tr>
<td>χ² / ndf</td>
<td>96.02 / 64</td>
</tr>
<tr>
<td>Width</td>
<td>9.479 ± 0.692</td>
</tr>
<tr>
<td>MP</td>
<td>42.39 ± 0.56</td>
</tr>
<tr>
<td>Area</td>
<td>2284 ± 76.3</td>
</tr>
<tr>
<td>GSigma</td>
<td>3.44 ± 1.67</td>
</tr>
</tbody>
</table>

Typical number of photoelectrons distribution
Fiber polishing and mirror

Fiber polishing in bundle by milling machine

After mirror coating by sputtering. Light yield *increase 70%* than without mirror.
Fiber Shaping

Glue fibers & hold together, Polishing by milling machine also

The unbundled end of fibers with mirror, separated into 3 different lengths for fiber insertion
Assembly tool

- Stack all the scintillator tiles, lead plates, and reflectors together
- Compress the module stack for 48 hours
Prototypes

• Three shashlik prototypes assembled in Shandong University.

Three shashlik prototypes material list:

<table>
<thead>
<tr>
<th>Prototype No.</th>
<th>WLS fiber</th>
<th>Fiber reflector</th>
<th>Scintillator</th>
<th>Painting</th>
<th>Reflecter layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>BCF91A</td>
<td>No reflector</td>
<td>Original</td>
<td>TiO2+glue</td>
<td>Paper</td>
</tr>
<tr>
<td>#2</td>
<td>BCF91A</td>
<td>Silver mirror</td>
<td>Enhanced</td>
<td>TiO2+glue</td>
<td>Paper</td>
</tr>
<tr>
<td>#3</td>
<td>Y11</td>
<td>Silver mirror</td>
<td>Enhanced</td>
<td>TiO2+glue</td>
<td>Paper</td>
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</tbody>
</table>
Cosmic ray test setup and typical photo-electron distribution

First module #1 result.

<table>
<thead>
<tr>
<th>h2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
</tr>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Sigma</td>
</tr>
</tbody>
</table>
Prototype module cosmic ray test result

Prototype #2 test result

Prototype #3 test result
### Cosmic ray test result

<table>
<thead>
<tr>
<th>Module No.</th>
<th>NPE</th>
<th>NPE (W/O TiO2)</th>
<th>WLS fiber</th>
<th>Scintillator</th>
<th>Fiber reflector</th>
<th>Painting</th>
<th>Reflector layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDU #1</td>
<td>229.2</td>
<td>BCF91A</td>
<td>Kedi</td>
<td>No mirror</td>
<td>TiO2+glue</td>
<td>Print paper</td>
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</tr>
<tr>
<td>SDU #2</td>
<td>439.5</td>
<td>BCF91A</td>
<td>Kedi(enhanced)</td>
<td>Silver mirror</td>
<td>TiO2+glue</td>
<td>Print paper</td>
<td></td>
</tr>
<tr>
<td>SDU #3</td>
<td>486.9</td>
<td>381.3</td>
<td>Y11</td>
<td>Kedi(enhanced)</td>
<td>Silver mirror</td>
<td>TiO2+glue (1:1)</td>
<td>Print paper</td>
</tr>
</tbody>
</table>

- Enhanced scintillator and mirror: light yield increase 95%
- Coating with TiO2: increase 26.2%
- Y11 compared with BCF91A: increase 17%
Summary

- All the machining accuracy is well controlled.
  - problem for tyvek punching resolved recently.

- Know well of assembling the shashlik module.

- maximum light yield near 500 photoelectrons for single muon in the best module.
  - Still lower than SoLID proposal.

- Finding the way to increase the light yield.

Thanks for your attention!
Thank You
Backups
PMT absolute gain and NPE (number of photoelectrons)

Single photoelectron spectrum

The fitting of the Pedestal and SPE

<table>
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<td>RMS</td>
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Gain = (ADC_{signal} - ADC_{pedestal}) × LSB/e

- LSB is the QDC least significant bit which is equal to 0.029 pC
- e is single electron charge.

Prototype NPE spectrum

NPE = Q / (e × Gain)

- Q is charge acquired from QDC with pedestal subtracted.
- Fitted by convolution of Gauss and Landau.